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# RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Navy Department

## BUFFETING OF EXTERNAL FUEL TANKS AT HIGH SPEEDS ON A GRUMMAN F7F-3 AIRPLANE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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# BUFFETING OF EXTERNAL FUEL TANKS AT HIGH SPEEDS ON A GRUMMAN F7F-3 AIRPLANE

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## SUMMARY

Attempts were made to alleviate the buffeting of external fuel tanks mounted under the wings of a twin-engine Navy fighter airplane. The Mach number at which buffeting began was increased from 0.529 to 0.640 by streamlining the sway braces and by increasing the lateral rigidity of the sway brace system. Further increase of the Mach number, at which buffeting began to 0.725, was obtained by moving the external fuel tank to a position under the fuselage.

## INTRODUCTION

High-speed combat aircraft have encountered serious buffeting in flight at high Mach numbers when carrying external stores. As a typical example of this condition the Grumman F7F-3 airplane encountered buffeting with the installation of 150-gallon fuel tanks mounted externally beneath the wings. This buffeting effectively limited the speeds to which the airplane could be flown with the tanks

installed.

At the request of the Bureau of Aeronautics, Navy Department, flight tests were conducted at the Ames Aeronautical Laboratory on a Grumman F7F-3 airplane to obtain information on the sources of the buffeting and on means for alleviating the buffeting.

## INSTRUMENTATION

Standard NACA continuous-film-recording instruments were used to record airspeed, altitude, free-air temperature, and the motion of the tank; 35-millimeter motion pictures were obtained of the tufts on the tank and surrounding structure.

An airspeed calibration, obtained on an XF7F-1 airplane by flying in formation with an airplane on which the airspeed installation was calibrated, was used for this investigation. It was considered that the errors involved in the use of this calibration and in extrapolating to the test Mach numbers were negligible.

The tufts for these tests were pieces of nylon parachute shroud line, wrapped securely at both ends, dyed black, and glued to the tank. These tufts were used as the wool yarns and other materials tested could not stand the severe turbulence encountered in the separated area.

Only the lateral motion of the tank was measured as preliminary observations by the pilot during buffeting

conditions showed the oscillations to be transverse.

## TESTS, RESULTS, AND DISCUSSION

The external stores used in these tests were standard Navy droppable 150-gallon Universal metal fuel tanks. For these tests, the tanks were reinforced by welding 0.090-inch chrome-molybdenum plates across the sway brace contact area to prevent denting by the sway brace pads in order to eliminate any deformation of the tank proper that may be due to the tank shake or buffet.

Two tank positions were investigated, one under the wing and the other under the fuselage (fig. 1). In the wing position, the tanks were mounted midway between the engine nacelle and the fuselage. The tops of the tanks were 16 inches below the lower surface of the wing with the tank center lines parallel to the wing chord line. In the fuselage position, the top of the tank was 4 inches below the fuselage with the tank center line parallel to the fuselage reference line.

Figure 2 is a sketch of the sway brace configurations tested, showing the cross sections of the various members. Figures 3 to 7 are photographs of the various tank and sway brace arrangements as installed on the airplane. The sway brace configurations are described in detail in the appendix.

An effort was made to duplicate the total preload exerted on the tanks by the sway braces for each configuration.

For the strap-type sway braces (configurations 1 and 2 of fig. 2), it was assumed that the center sway brace adjustment screw (figs. 3 and 4) exerted one-half the total preload on the tank and the auxiliary lateral braces the other half. This was considered when torquing the adjustment screws on the service-type sway braces (configurations 3 and 4 of fig. 2). When the original service installation (configuration 4, fig. 2) was set up with equivalent forces, it was considered too flexible for flight. Accordingly, the rubber was removed from the sway brace pads and the torque on the adjustment screws increased by 50 percent.

Navy Bureau of Ordinance Mark-51, modification 12 bomb racks were used in the wing positions and a Mark-D6 bomb rack was used in the fuselage position. The test airplane came equipped with these bomb racks in the positions described.

During the wing test program, in a dive to an indicated Mach number of 0.61, one of the Mark-51 bomb racks released a tank while the manual and electric releases were inoperable. Further investigation showed that these bomb racks had a tendency to inadvertently release the store when subject to a sustained period of buffeting. For safety in the course of this investigation, it was necessary to insert a bolt in the release mechanism in such a manner as to prevent the release jaws from opening.

## Buffeting Tests

The buffeting tests were conducted by obtaining continuous records in dives of the Mach number, tuft behavior, and motion of the tank, Most of the tests in the wing position were made with only the right wing tank installed as minor differences in rigging between tanks resulted in buffeting variations not otherwise obtained. The results of these tests are summarized in table I which lists, for the various configurations, the average Mach numbers at which the tanks began to shake and the average highest Mach numbers attained in the dives. The latter values represent approximately the maximum degree of buffeting the pilot considered tolerable.

Effect of sway bracings - Comparison of the data for configurations 3 and 4 shows that the addition of the auxiliary braces increased the Mach number at which buffeting started by 0.077. It was noted previously that for configuration 4, the total preload was greater than for configuration 3. These results demonstrate the importance of adequate lateral bracing for the tanks. The original service configuration, which depends essentially on the rigidity of the central columns for lateral bracing, would appear from these results to be deficient in that regard.

Further evidence of the importance of lateral rigidity was obtained in a dive with a tank under each wing panel,

sway braced as in configuration 2. In this dive, according to the pilot's observations, the left tank started to buffet at a Mach number of 0.06 lower than the right tank. The nominal preload on the left tank was found to be approximately 6 percent less than that on the right tank.

The streamlining of the sway braces of approximately the same lateral rigidity (configurations 3 to 1) effected an increase in the buffet Mach number of 0.034.

Tuft studies.- Tuft studies were used to determine the flow around the tanks in the wing and fuselage positions. Figure 8 shows two enlargements from 35-millimeter photographs of the tuft action around the tank and pylon fairings of the wing tank position, sway brace configuration 1. Figure 8(a) indicates the tuft action at low speed ($M \approx 0.246$). Figure 8(b) indicates tuft action at a Mach number of approximately 0.64 during severe buffeting conditions.

In the interpretation of the tuft action, "flow separation" indicates the flow conditions existing when the tufts are rotating or pointing in random directions, "severe turbulence" indicates incipient flow separation.

Figure 9 is a sketch of the tank suspended below the wing showing the maximum area of flow separation on the fuselage side of the tank for all configurations tested. This area was determined from the motion pictures and from the marks left on the tank by the severely oscillating tufts.

Configuration 1.- The tuft studies indicated that at all speeds above the lowest test speed (150 mph) the flow over the tanks was unsteady. The flow became progressively worse as the speed was increased until at a Mach number of 0.640 separation occurred over the area shown in figure 9. The flow separation at the aft end of the pylon fairing and between the sway braces was particularly violent, becoming more violent with further increase in Mach number. The tank shaking occurred at the same Mach number as the separation began.

Configuration 2.- For configuration 2, which differed from configuration 1 only in the degree of fairing of the sway braces, the flow characteristics were essentially the same as for configuration 1. Flow separation and its accompanying tank shaking occurred at a Mach number of 0.620, 0.02 lower than for configuration 1.

Configuration 3.- The tuft studies for configuration 3 (appendix and fig. 2 for configuration details) indicated very unsteady flow from 150 miles per hour to a Mach number of 0.606 where separation took place. Severe turbulence was indicated in the vicinity of the rear sway brace from approximately 0.50 Mach number to 0.606 Mach number. Shaking of the tank occurred at M=0.606.

Configuration 4.- Configuration 4 differs from configuration 3 only in its lateral rigidity. The flow characteristics are essentially the same as for configuration 3. Flow separation occurred at $M \approx 0.60$ but the tank shaking began at 0.529, while the tufts indicated severe turbulence or incipient separation. The shaking of configuration 4 before flow separation occurred was believed to be accentuated by the relatively low lateral rigidity of the installation.

During the buffeting conditions the pilot noted shaking of the entire airplane. It was the pilot's opinion that the airplane shaking was due to tail buffeting.

Fuselage mounting.- The shaking of the tank in the fuselage position was found to be similar in magnitude and characteristics to the shaking realized in the wing position. No shaking of the airplane was noted by the pilot. The tuft pictures indicate an incipient separation along the top of the tank and aft of the rear sway brace at Mach numbers of approximately 0.685. The tank position recorder indicated that the tank started to shake slightly at this time. The dives were continued to Mach numbers of approximately 0.725. The dives were terminated at these speeds because the pilot believed he had reached the limit diving speed of the airplane with the tank on. Only a slight tremble was felt in the airplane at these speeds.

At the maximum Mach numbers attained, the separated area had extended forward and downward from the rear sway brace area. Figure 10 shows the area of flow separation at these maximum speeds. At no time was the flow separation as violent as that observed in the wing tests. No separation was indicated along the fuselage.

The average maximum Mach numbers attained for this tank position were used to compare with the buffet Mach numbers for the tanks in the wing positions because of the similarity in flow separation for the two positions at the Mach numbers chosen.

## Velocity Distribution In Wing Installation

Figure 9 indicates that the flow separation in the wing position extends forward to a point between the front and rear sway braces at approximately 30 percent of the wing chord. Since the maximum thickness of the wing is at approximately 30 percent of its chord and the maximum thickness of the tank is just below this 30-percent-chord point, it was decided to compute by the method of reference 1 the velocity distribution in this area in an attempt to obtain a value of the critical Mach number in that region.

Figure 11 shows the result of the analysis of the velocity distributions at a station 30 percent of the wing chord and in the area between the right engine nacelle and

the fuselage. Assuming the nacelle and fuselage to be bodies of revolution with definite fineness ratios, lines of constant velocity ratio were drawn for the nacelle, fuselage, and wing (references 1, 2, and 3). From these velocity distributions and using the method of superposition and interference shown in reference 1, it is possible to calculate a low-speed pressure coefficient from which a value of critical Mach number may be determined. (See fig. 4, reference 1.) For example, the critical Mach number at point A figure 11, neglecting interference due to sway braces and power effects, would be as follows:

| | |
|---|---|
| Velocity increment due to nacelle | 0.070 V |
| Velocity increment due to fuselage | .016 V |
| Velocity increment due to wing | .100 V |
| Velocity increment due to tank | .070 V |
| Velocity increment due to fairing | .200 V |

Net velocity is $(1+0.070+0.100+0.016+0.070+0.200)$ $V = 1.456$ V

Low-speed pressure coefficient = $(1.456)^2 = 2.12$

from fig. 4 reference 1, the critical Mach number would be 0.590. This calculated critical Mach number is in good agreement with the Mach number at which the violent disturbances in flow were indicated by the tuft studies. The power effects were considered negligible as there was no appreciable difference in the Mach numbers at which buffeting began when the propeller was operating at normal rated power and when the propeller was feathered. No attempt was made to evaluate

the velocity distribution resulting from the various sway brace configurations.

## CONCLUDING REMARKS

The slightly modified service sway brace installation (configuration 4) was used as a base of comparison in this investigation. An increase in buffet Mach number of 0.077 was obtained by increasing the lateral rigidity of the sway braces. A further small increase in the buffet Mach number of 0.034 was obtained by streamlining the sway braces. The result of increasing the lateral rigidity and streamlining the sway braces resulted in an increase in buffet Mach number of 0.111.

The results of the velocity distribution study show that the external fuel tanks, mounted as in the wing position on the Grumman F7F-3 airplane, will have low critical Mach numbers due to the interference effects of the wing, engine nacelle, and pylon fairing. These effects were eliminated by mounting the external fuel tank below the fuselage. The resulting increase in critical Mach number was 0.196.

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# APPENDIX
## TEST CONFIGURATIONS OF EXTERNAL STORES INVESTIGATED

1. Strap-type sway brace - faired (fig. 3)
   - (a) Flat strap-type sway brace faired smooth with surfacing putty and covered with fabric
   - (b) Steel streamlined tubing auxiliary sway braces
   - (c) Rubber, 3/32-inch-thick, between sway brace and tank
   - (d) Adjustment screws torqued to exert a force of 9000 pounds per sway brace on tank
2. Strap-type sway brace, unfaired (fig. 4)
   - (a) Flat strap-type sway brace, no fairing
   - (b) Steel streamlined tubing auxiliary sway braces
   - (c) Rubber, 3/32-inch-thick, between sway brace and tank
   - (d) Adjustment screws torqued to exert a force of 9000 pounds per sway brace on tank

   Note: Pylon access hole, shown open in figure 4 was closed during flight tests.
3. Service-type sway brace - modified (fig. 5)
   - (a) Round service-type sway braces with rubber on the bottom of the sway brace pads
   - (b) Round auxiliary sway braces
   - (c) Adjustment screws and auxiliary braces torqued to exert a force of 9000 pounds per sway brace on tank

4. Service-type sway brace (fig. 6)

(a) Round service-type sway braces

(b) Rubber removed from sway brace pads

(c) No auxiliary braces

(d) Adjustment screws torqued to exert 13,000 pounds per sway brace on tank

## REFERENCES

1. Katzoff, S., and Finn, Robert S.: Effects of External Fuel Tanks and Bombs on Critical Speeds of Aircraft. NACA CB No. L5H27, 1946.

2. Robinson, Russell G., and Wright, Ray H.: Estimation of Critical Speeds of Airfoils and Streamline Bodies. NACA ACR, March 1940.

3. Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA ACR No. L5C05, 1945.

TABLE I.- COMPARISON OF BUFFET MACH NUMBERS OBTAINED FOR VARIOUS SWAY BRACE CONFIGURATIONS

| Sway brace configuration | Average Mach number at which buffeting began ($M_{buffet}$) | Average maximum Mach number attained in dives ($M_{max}$) |
|---|---|---|
| No. 1 | 0.640 | 0.655 |
| 2 | .620 | .649 |
| 3 | .606 | .656 |
| 4 | .529 | .615 |

The above data are for the F7F-3 airplane with the right tank in place. Dives from 15,000 feet normal rated power.

# FIGURE LEGENDS

Figure 1.- Test locations of 150-gallon droppable metal auxiliary fuel tanks mounted externally on a Grumman F7F-3 airplane.

Figure 2.- Sketch of sway brace configurations tested showing the cross sections of the various members.

Figure 3.- Wing position, sway brace, configuration 1. (a) Front view. (b) Rear view.

Figure 4.- Wing position, sway brace, configuration 2. (a) Front view. (b) Rear view.

Figure 5.- Wing position, sway brace, configuration 3. (a) Front view. (b) Rear view.

Figure 6.- Wing position, sway brace, configuration 4. (a) Front view. (b) Rear view.

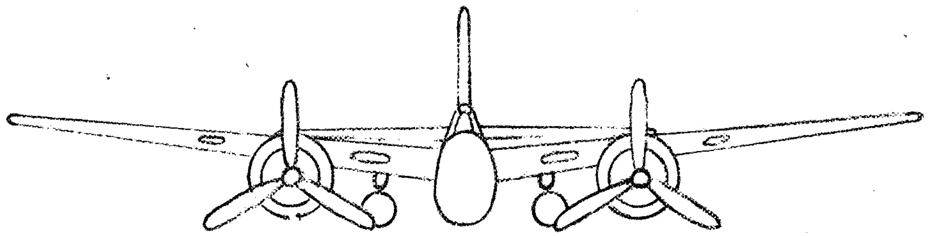
Figure 7.- Fuselage position, sway brace, configuration 4.

Figure 8.- Tuft study of auxiliary fuel tank in flight at various Mach numbers, wing position, Grumman F7F-3 airplane. (a) $M \approx 0.246$ (b) $M \approx 0.640$.

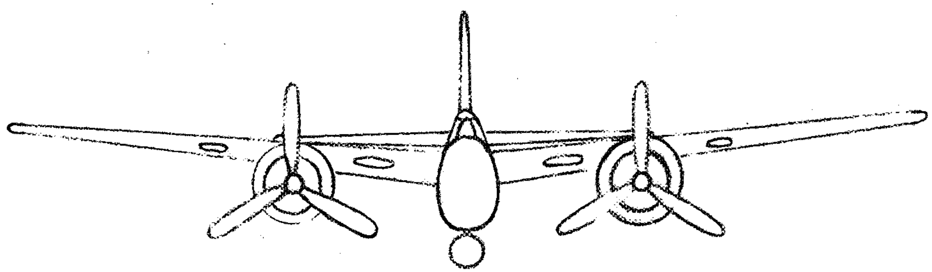
Figure 9.- Flow separation at high speed around an auxiliary fuel tank mounted under the wing of a Grumman F7F-3 airplane. $M \approx 0.640$.

Figure 10.- Flow separation at high speed around an auxiliary fuel tank mounted under the fuselage of a Grumman F7F-3 airplane. $M \approx 0.725$.

Figure 11.- Velocity-ratio distribution in the region of the wing external store attachment position. 30 percent wing chord, Grumman F7F-3 airplane. $C_l = 0.10$.



Wing-tank position



Fuselage tank position

Fig 1.- Test locations of 150-gallon droppable metal auxiliary fuel tanks mounted externally on a Grumman F7F-3 airplane.

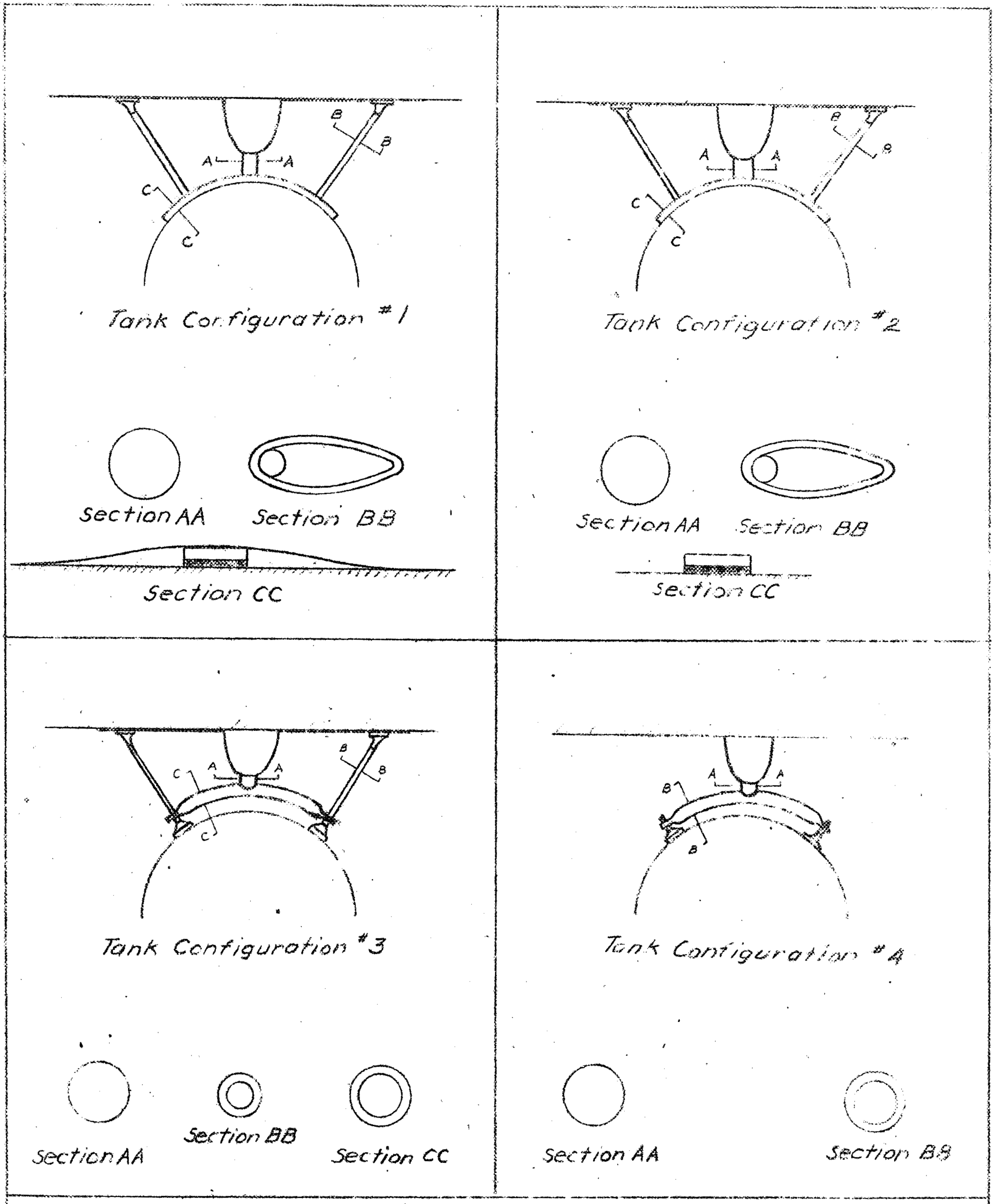
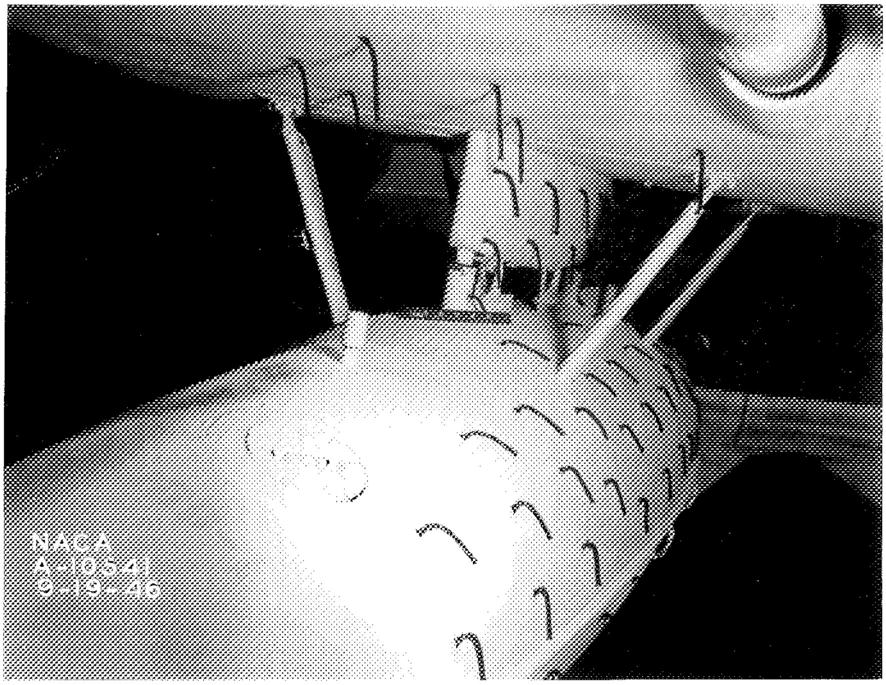
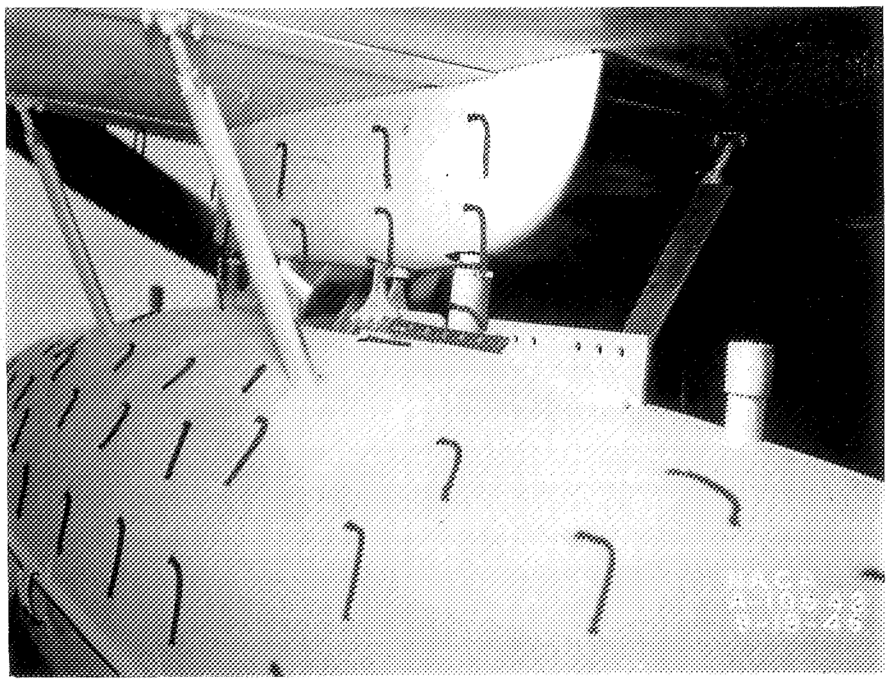



Fig. 2.- Sketch of sway brace configurations tested showing the cross-sections of the various members.

[redacted]



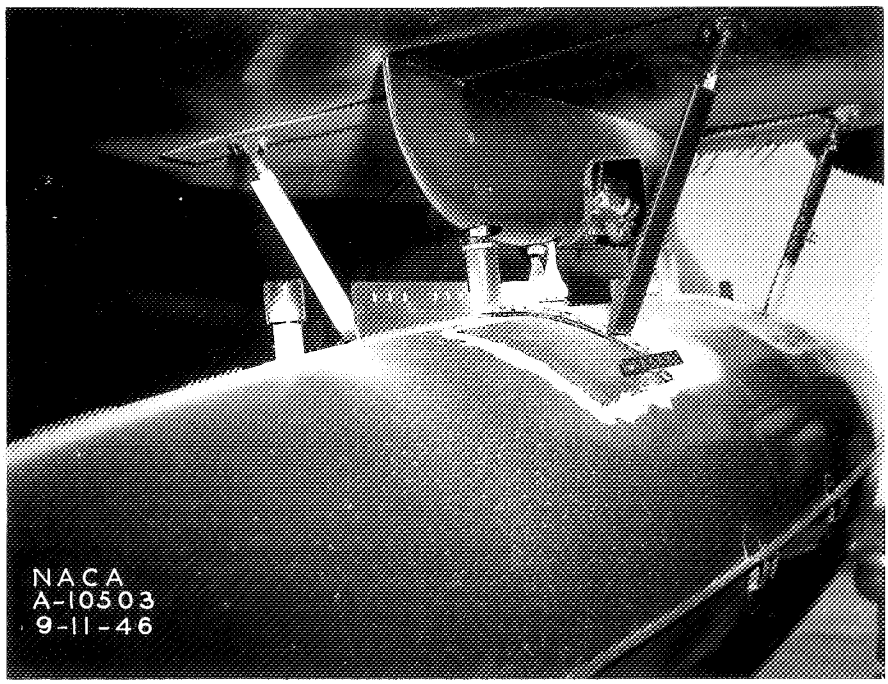

(a) Front view.



(b) Rear view

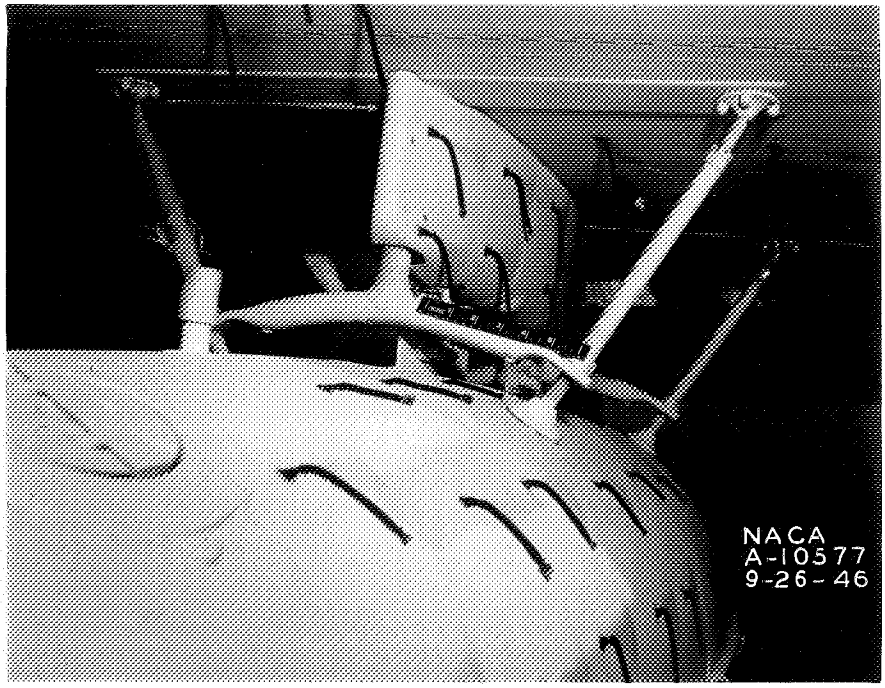
Figure 3.- Wing position, sway brace, configuration 1.


(a) Front view

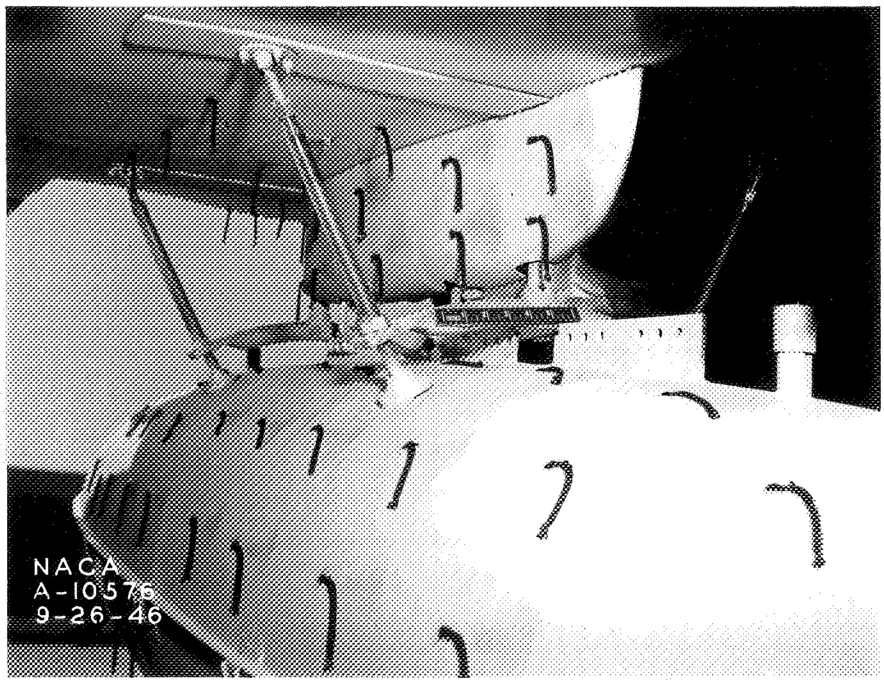



(b) Rear view

Figure 4.- Wing position, sway brace, configuration 2.



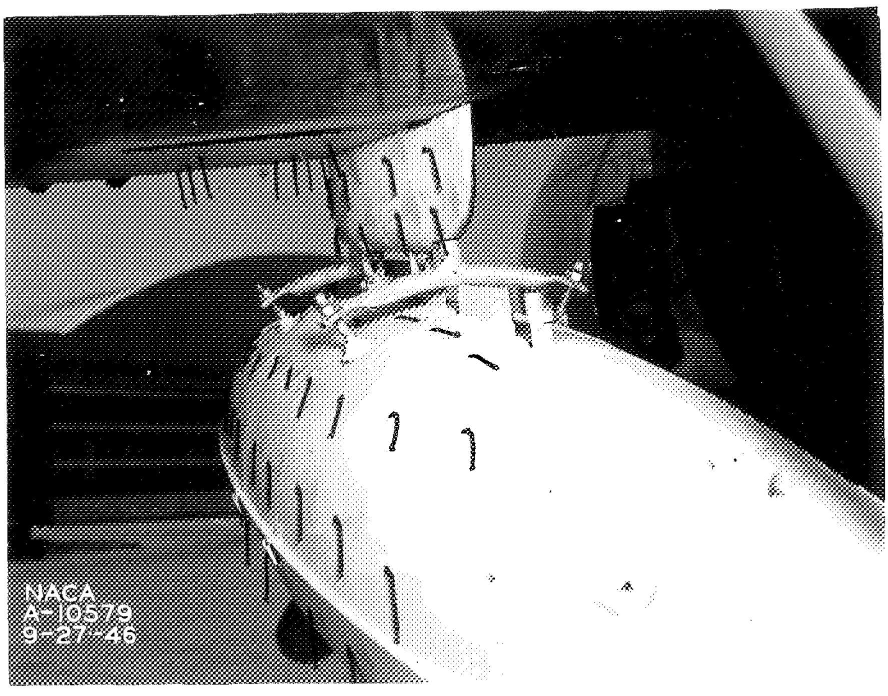

(a) Front view




(b) Rear view

Figure 5.- Wing position, sway brace, configuration 3.


(a) Front view.




(b) Rear view.

Figure 6.- Wing position, sway brace, configuration 4.

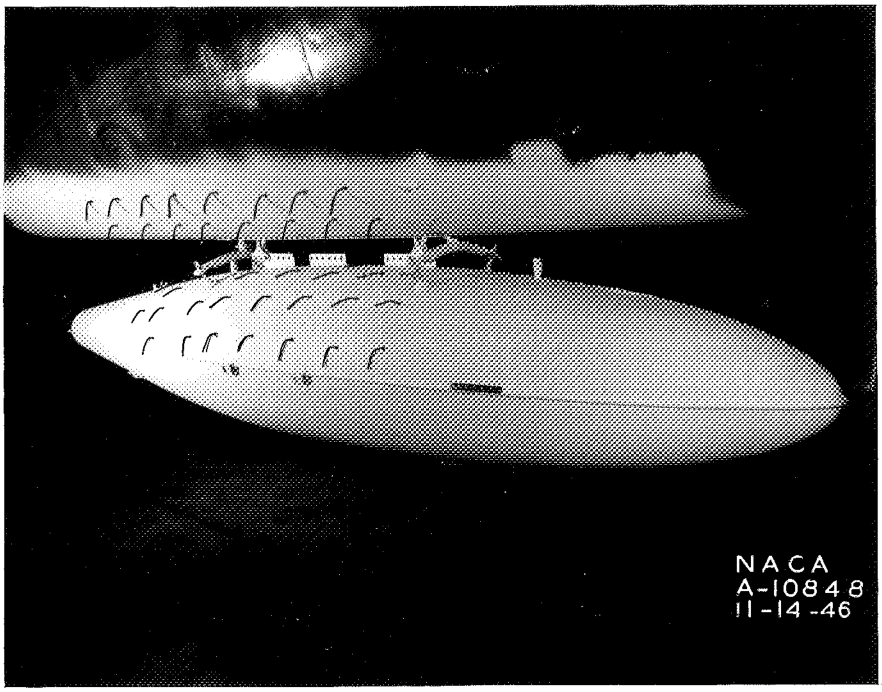
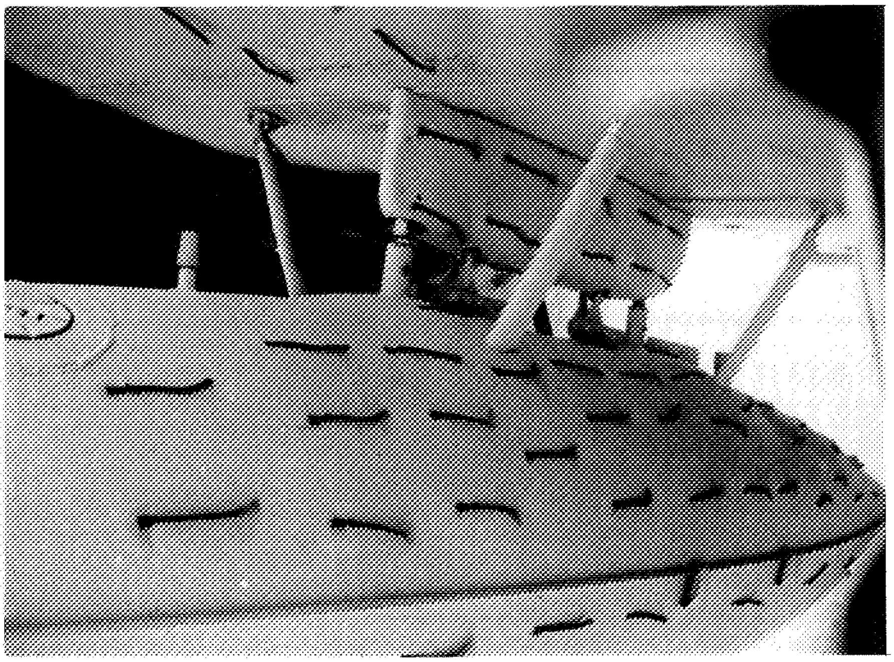
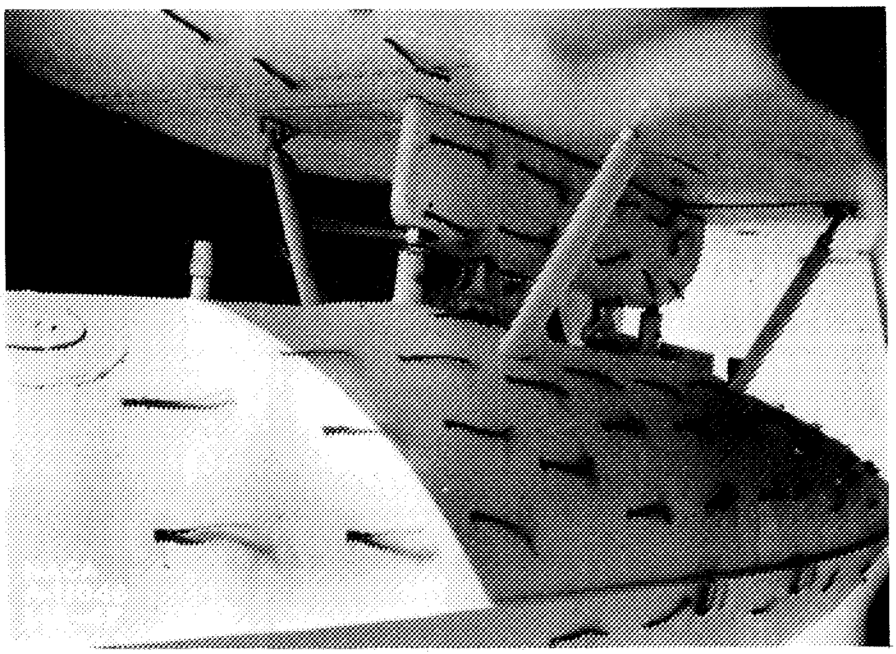



Figure 7.- Fuselage position, sway brace, configuration 4.



(a) M ≈ 0.246



(b) M ≈ 0.640

Figure 8.- Tuft study of auxiliary fuel tank in flight at various Mach numbers, wing position, Grumman F7F-3 airplane.

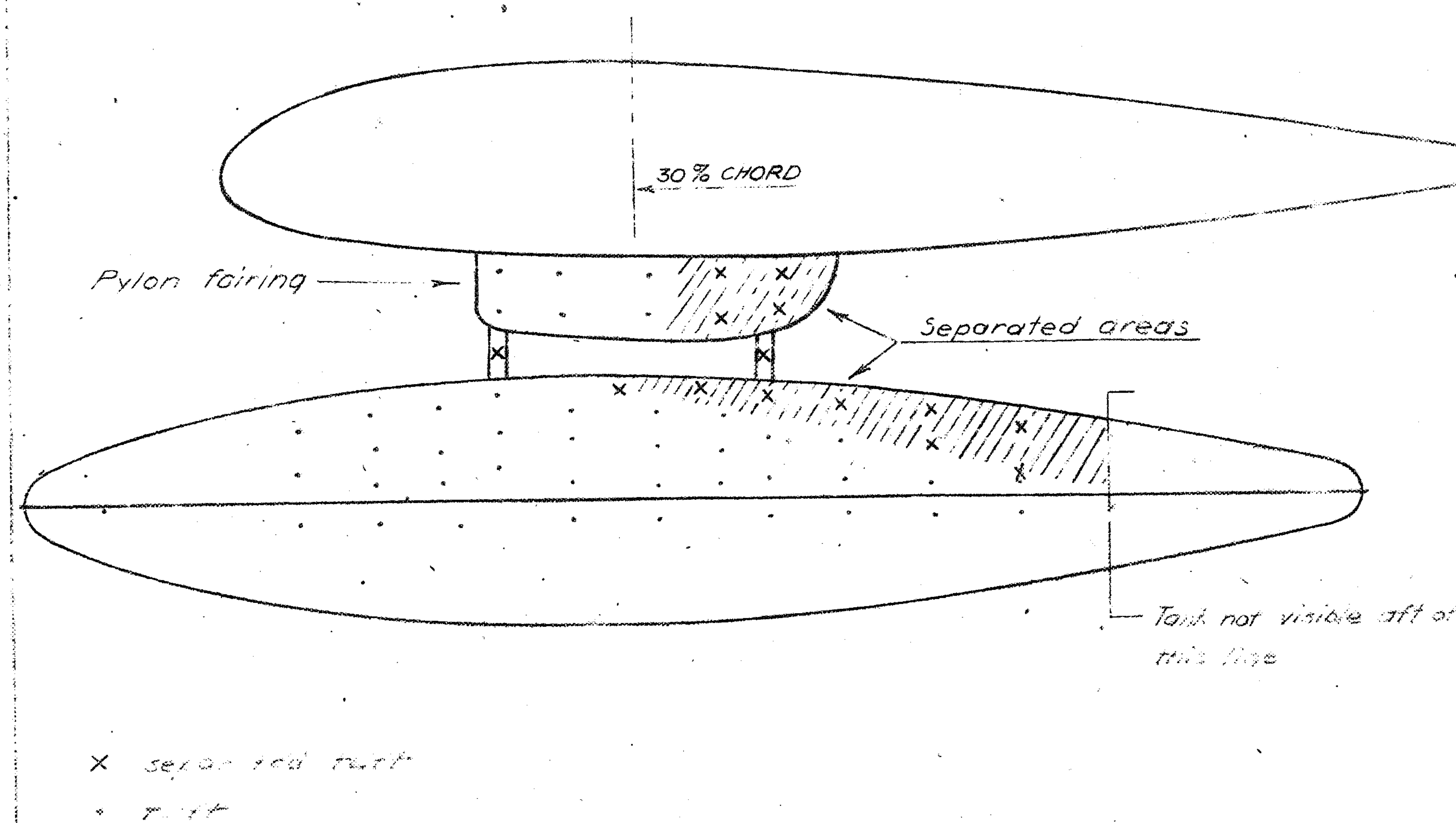



Fig 9.- Flow separation at high speed around an auxiliary fuel tank mounted under the wing of a Grumman F7F-3 airplane. $M \approx 0.640$

[redacted]

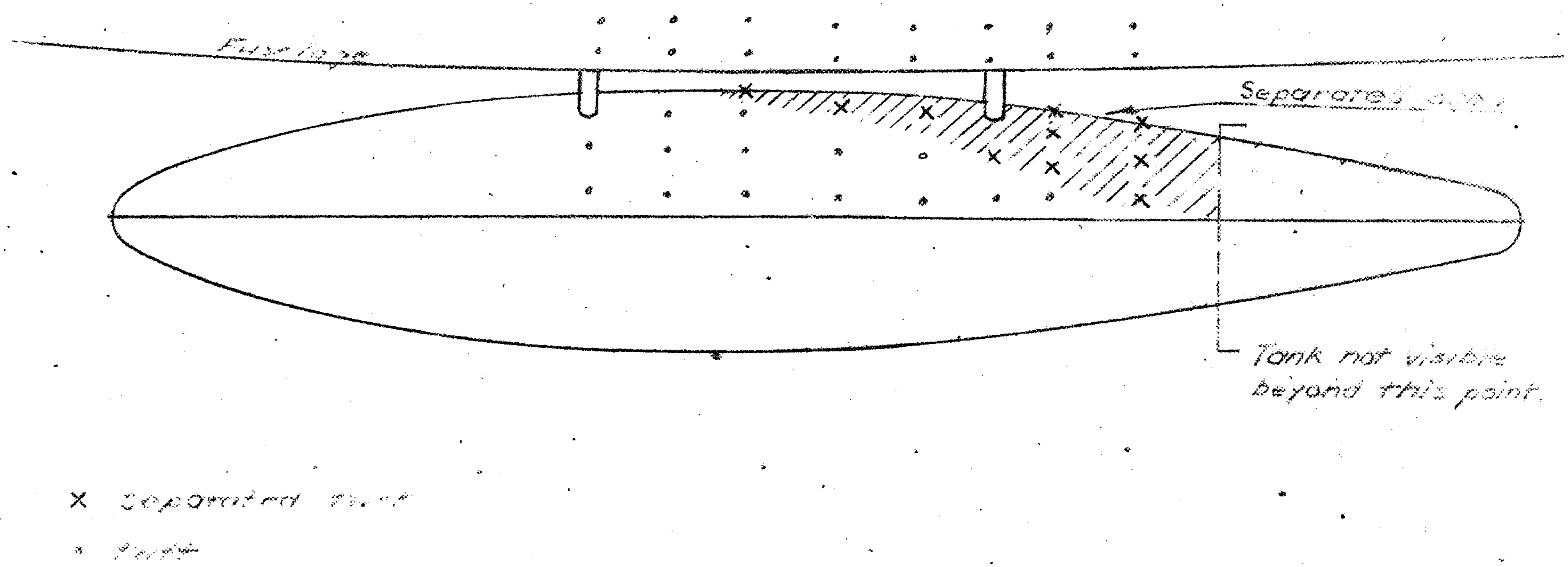



Fig. 10.- Flow separation at high speed around an auxiliary fuel tank mounted under the fuselage of a Grumman F7F-3 airplane. $M \approx 0.725$.

[redacted]

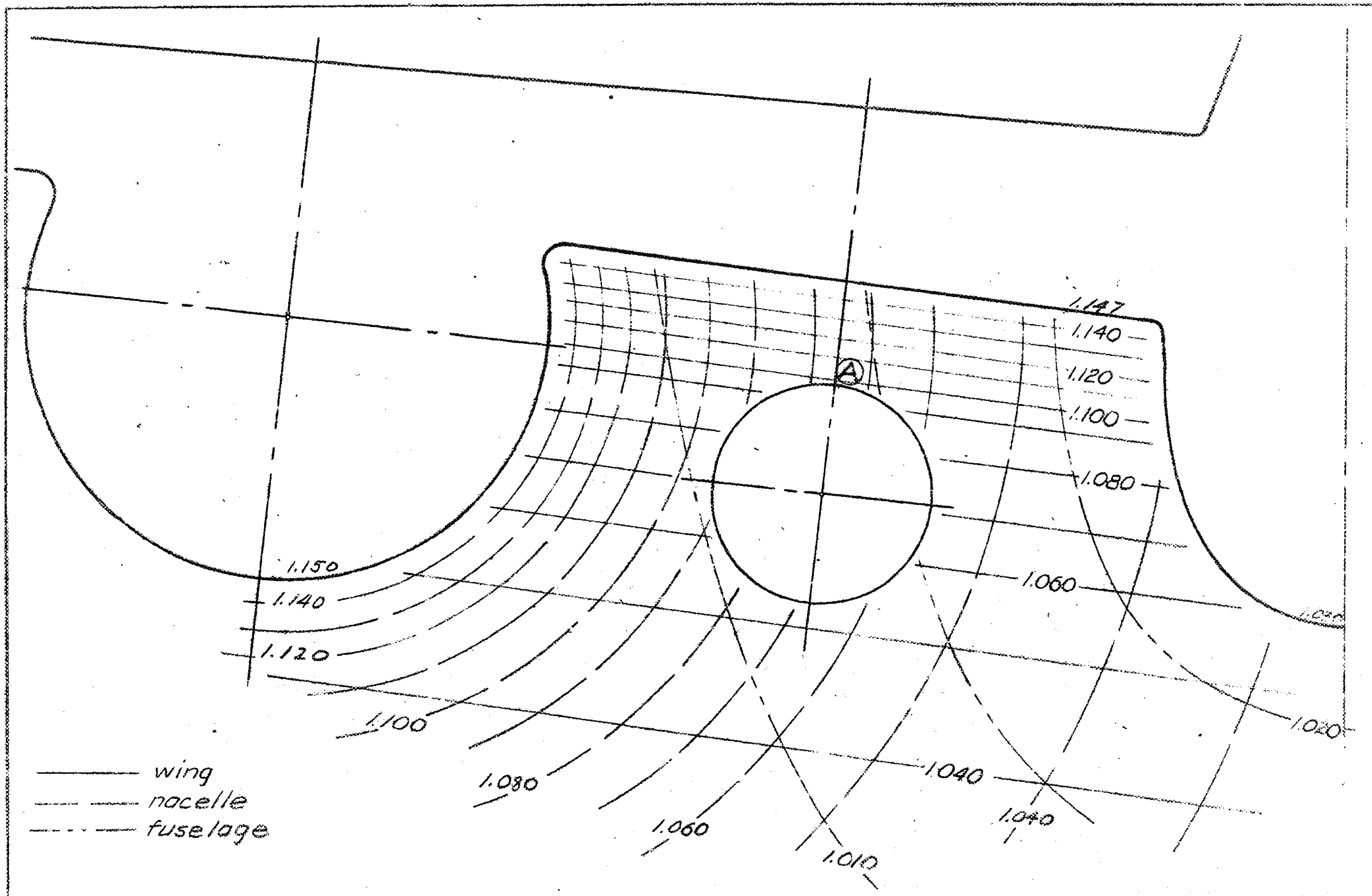



Fig. 11 - Velocity-ratio distribution in the region of the wing external store attachment position. 30% wing chord, Grumman F7F-3 airplane. $C_L = 0.10$.